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No. 155

SYSTEMS ENGINEERING AS APPLIED TO COMMAND AND CONTROL AND NAVAL WARFARE

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Beijing XITONG GONGCHENG LUNWENJI [SYSTEMS ENGINEERING PAPERS] in Chinese Jul 81, Science Press, pp 50-55, 56-61, 62-66, 67-71

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COMMAND CONTROL, NAVAL WARFARE TOPICS ANALYZED

Submarine-Surface Ship Combat Modeling

Beijing XITONG GONGCHENG LUNWENJI [SYSTEMS ENGINEERING PAPERS] in Chinese
Jul 81, Science Press, pp 50-55, 56-61, 62-66, 67-71

[Article by Xu Xinwen [6079 1800 2429], Naval Academy, Chinese People's Liberation Army : "Simulation of Submarine-Surface Ship Combat"]

[Text] I. Introduction

Combat between submarines and surface ships is a form of naval combat. As in any other combat, the commander's basic task is decision-making. Although there are a multitude of specific decisions, they boil down to decision on the basic questions of (1) whether to attack, and (2) how to attack. Accordingly, a discussion of decision-making should be based on the fundamental objective of combat, i.e., to destroy the enemy and preserve oneself. In combat between submarines and surface ships, the submarine commander tries to sink as many surface ships as possible while minimizing damage to the submarine, while the surface ship commander does everything possible to sink the submarines while minimizing his own losses. We may conclude that one combatant's victory is the other's loss. Taking as a criterion of effectiveness the ratio of the two combatants' average number of victories, we have

$$a = \frac{P}{Q}$$

where P is the submarines' average number of victories and Q is the surface ships' average number of victories.

The submarines strive to maximize the value of a and the surface ships to minimize it. Command in combat has always been based on the commander's skill and experience. The making of quantitative analyses of the problem of destroying the enemy and preserving oneself, i.e. numerical forecasts of victory or defeat, for the commander to use in decision-making is an activity which has developed during the last few decades. This paper is an attempt to use the Monte Carlo method, combined with applied game theory, in a preliminary investigation of combat between submarines and surface ships.

II. Conditions

A. Surface Ships

Surface ships generally operate in small groups of two or three; the usual surface ship capabilities and operational procedures may be assumed to be the following.

1. They zigzag when crossing areas of possible enemy submarine activity, otherwise they take a straight course.

2. When a group which has not received an antisubmarine warfare assignment discovers a submarine ahead of it, it uses its weapons to attack the submarine; when it discovers the submarine at a large bow angle it takes evasive action.

3. After attacking a submarine, the surface ships take evasive action and reload their ASW weapons, attacking again if they have the opportunity.

B. Submarines

Conventionally-powered submarines generally operate in small groups of three to five; submarine operating capabilities and procedures are generally as stated below.

1. They lie in wait in a specified sea area. There are no command relationships between submarines at sea: on the basis of general orders given by the shore-based command, the submarines first proceed to an area ahead of the surface ships, then deploy in a specified formation and approach the enemy at slow speed.

2. When the submarines detect the surface ships, they approach them at right angles and determine the target ships' speed and heading.

3. When the speed and heading have been determined, the submarines calculate and take up torpedo launching positions, then launch their torpedoes.

4. When the surface ships are zigzagging, the submarines approach them on a course perpendicular to their overall heading, moving into a course toward a torpedo firing position at intermediate distance, and attempt to launch their torpedoes before the surface ships can change course again.

5. If the surface ships' course after turning exceeds a critical angle, the submarines continue to approach them at intermediate speed, because if the surface ships suddenly turn toward the submarines, the latter may still have a chance to attack at close range.

III. Solution Procedure

The analytical method or the simulation method may be used for numerical analysis of the course of combat. Using a purely analytical method to describe the combat between submarines and surface ships is rather complex, for the following reasons.

1. The combat is a multistep situation and must be solved using game trees: the set of all terminal vertices {t} for all possible game situations must be watched one-to-one with the payoff set {w}.

2. If we take the period of time before the submarines or surface ships discover their adversaries as the initial game move, then for a simple situation the two players' strategies are discrete and finite. The surface ships may sail a straight course or zigzag, while the submarines can take up any one of a countable set of n waiting deployments.

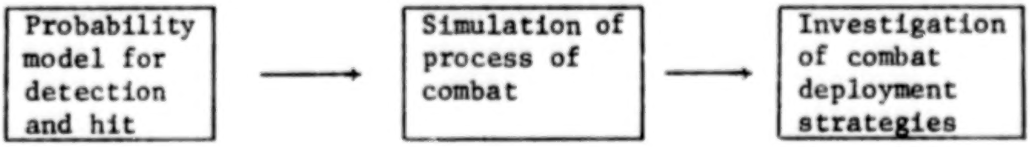
3. After the submarines or surface ships detect the enemy, then each of them will adopt a suitable strategy in the process of continuous maneuvering; the set of strategies will be infinite, making it difficult to use the game tree approach.

4. If we simplify the engagement in order to seek an approximate solution by specifying that the submarine and the surface ships must approach each other and may not withdraw, but must seek a decision, this simplified process can be converted to a game in a unit square. Assume that at a certain time the distance between the combatants is 1. The submarines will use their weapons at a distance x, $0 < x \leqslant 1$. The surface ships will use their weapons at a distance y, $0 < y \leqslant 1$. Thus the two players' strategies reduce to selecting the distances (x or y) within the area [0, 1] at which they will use their weapons, and we thus have a game in a unit square. Then, if we let the probability that each side destroys the other when using its weapons be a function p of the range, and if we select strategies F and G regarding the distance at which each side opens fire, then the submarines' victory function and expectation are:

$$H(x, y) = \begin{cases} 1 - (1 - p(x))p(y), \text{ 当 } x > y \text{ 时}, \\ 1 - p(y), \text{ 当 } x \leqslant y \text{ 时}, \end{cases}$$

$$H(F, G) = \int_0^1 \int_0^1 H(x, y)\,dF(x)\,dG(y).$$

But even if we simplify the process in this manner, it is still complex to obtain a numerical solution for the game. Accordingly, in this article we have decided to use a procedure more amenable to numerical solution as follows.


Probability model for detection and hit
Simulation of process of combat
Investigation of combat deployment strategies

Thus we use a probability approach, use the Monte Carlo method to simulate the random process of combat, develop statistics on the simulation results, and use these statistics to obtain average with ratios and construct payoff matrices for the submarines' different deployments against surface ships, thus obtaining a solution for the two-person finite game.

A. Statistical Model

Submarines and surface ships both use sonar to detect each other, and we may consider that their probabilities of detecting each other within direct propagation range (i.e. ignoring sea-bottom reflection and focusing zones) are given by the following formula:

$$p(x) = 1 - \exp\left(-\int_0^r \lambda(t)\,dt\right),$$

where $\lambda(t)$ is the instantaneous detection probability, which can be approximated by a quadratic function of the reflected wave energy $E(t)$ as follows:

$$\lambda(t) = AE(t) + BE^2(t)$$

and

$$E(t) = \begin{cases} 40\log\left(\frac{r}{R}\right), & (r < R), \\ 0, & (r \geqslant R). \end{cases}$$

Of course, if we use statistical data on actual observation distances, we can also directly derive a formula relating detection probability to distance by using regression analysis.

We compile discrete data for N observations over target detection ranges, letting n_i be the number of times the targets were detected at distance r_i. Since the target is only detected when approaching, the detection probability p_i is:

$$p_1 = \frac{n_1}{N},$$

$$p_2 = \frac{n_2}{N}\frac{1}{(1-p_1)},$$

$$\vdots$$

$$p_i = \frac{n_i}{N}\frac{1}{(1-p_1)(1-p_2)\cdots(1-p_{i-1})}.$$

We introduce x, such that $x = \frac{r}{R}$, where R is the maximum target detection distance, and apply the method of least squares, obtaining

$$p = a_0 + a_1x + a_2x^2 + a_3x^3.$$

The coefficients a vary with the observational data. According to our data and computations, a_0 and a_2 are approximately equal to 1 and -1 respectively, and a_1 and a_3 to approximately zero. Accordingly we obtain the following formula relating target detection probability to instantaneous range:

$$p(r) = 1 - x^2 = 1 - \left(\frac{r}{R}\right)^2$$

The weapon error against the target is normally distributed and its density function is

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{x^2}{\sigma^2}\right),$$

where σ is determined by weapon dispersion and target dispersion, i.e. by the capabilities of the weapon and observing equipment and the proficiency of the manning personnel. If the definite integrals of the density function are found in a given region for different weapons and targets, the weapon hit probabilities can be obtained.

B. Combat Simulation

Simulation of the encounter between a submarine and a surface ship begins with a random initial state before target detection. The process as a whole includes: target detection; maneuver to take up positions suitable for use of weapons by each of the combatants; use of the weapons; ultimate determination of the results of use of the weapons.

In order to simplify the simulation process, we modeled the various pure game situations composed of the two combatants' strategies before mutual detection. Before the group of surface ships detects the target they may use the strategy of sailing a straight course or zigzagging. Before the submarines have detected their targets they may use three deployment strategies: line abreast, V formation, or inverted V formation, so that there are six pure situations. We carried out 1,500 simulation runs with these 6 pure situations. Most of them involved a combat maneuver process following target detection, but in some of them the surface ships passed out of the submarines' zone of action before either combatant discovered the other, so that no encounter resulted.

When the surface combatant group was zigzagging, the simulation was time-stepped with a 2-minute interval, and event-stepping was used only in a few cases. When the surface combatant group was sailing a straight course, the simulation process was event-stepped, with time-stepping inserted in individual subroutines. A block diagram of the procedure is appended ([Figure 1.1]; I is the sequential number of the simulation run, T is the time, X and Y are the position coordinates, H is the heading, TQ is the turning time, X_d is the bow angle, ΔT is the time interval, and N is the total number of simulations).

Key:
- a. Submarine initial state valuation variables X,Y,H
- b. Enemy initial state valuation random variables X,Y,H,TQ
- c. Distance apart D
- d. Enemy zigzagging
- e. Enemy detected?
- f. Position of two sides after ΔT
- g. Submarine determines position of enemy
- h. Positions of two sides after ΔT
- i. Distance apart D
- j. Enemy zigzagging
- k. Is D < D for attack by submarine?
- l. Hit?
- m. Detected by enemy?
- n. Is X_d less than bow angle for attack on submarine?
- o. Is D < D for attack on submarine?
- p. Attack preparations complete?
- q. Submarine hit?
- r. Do two sides disengage?
- s. Average cumulative result, print out, stop
- t. Cumulate results

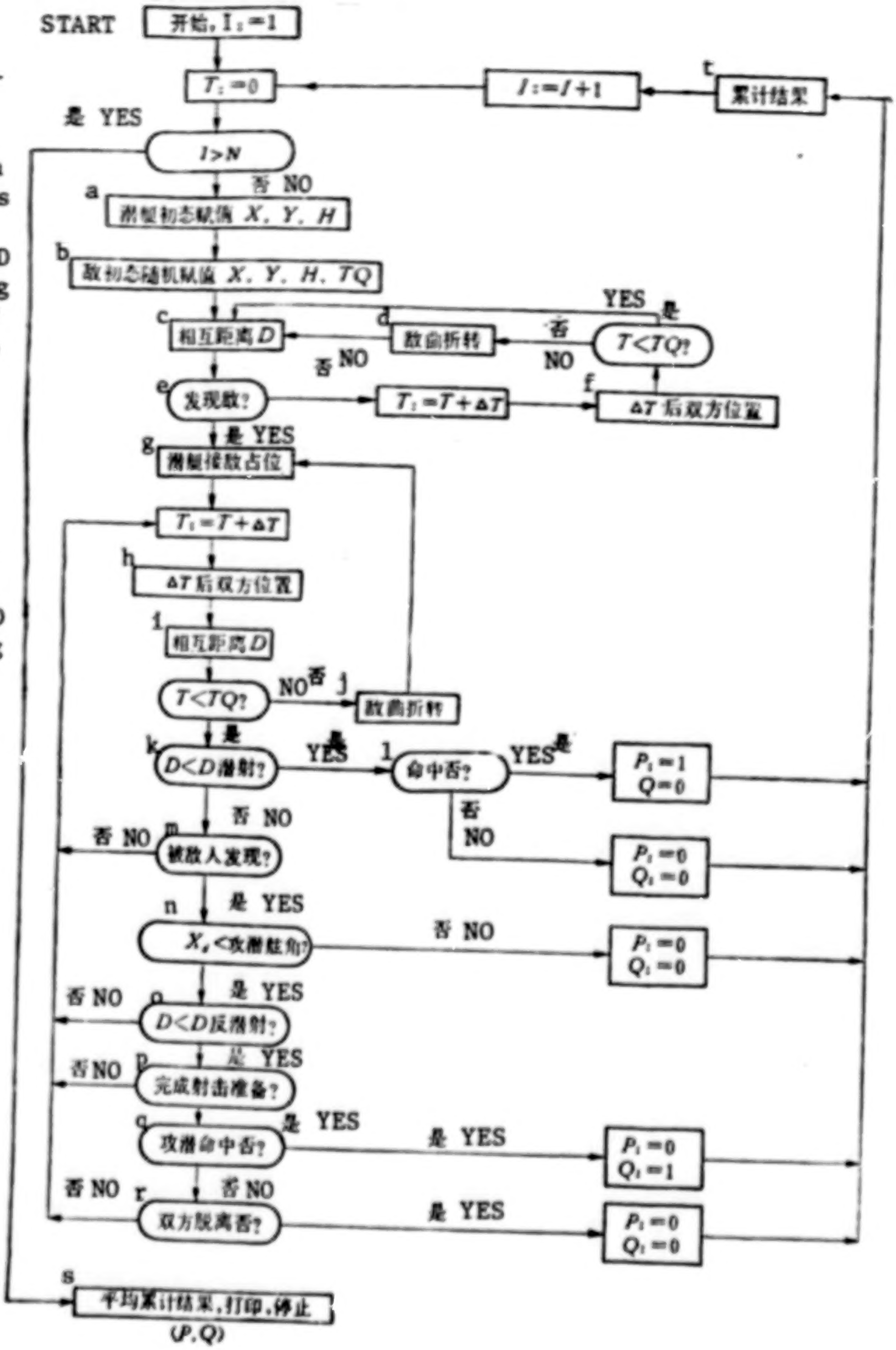


Figure 1.1

C. Investigation of the Game

The statistical results yield a two-person game between submarines and surface ships:

$$G = \{S_1;\ S_2;\ A\},$$

where $S_1 = \{\alpha_1, \alpha_2, \alpha_3\}$, and α_1, denotes line abreast deployment of the submarines, α_2 denotes V formation, and α_3 denotes inverted V deployment; $S_2 = \{\beta_1, \beta_2\}$, where β_1 denotes use of a straight course by the surface ships and β_2 denotes zigzagging; $A = (a_{ij})$, where $a_{ij} = P_{ij}/Q_{ij}$ and P_{ij} and Q_{ij} are the statistical modeling results.

Given the above conditions, the game has an optimum pure strategy solution:

$$\max_i \min_j a_{ij} = \min_j \max_i a_{ij} = v = a_{22}$$

This means that for the submarines to win the maximum number of victories with minimum losses they should deploy in V formation, while for the surface combatants to sink as many submarines as possible while minimizing hits by the submarines, they should zigzag.

IV. Preliminary Results

The combat simulation results can be used as a quantitative reference data for decision by the commander, i.e. when he is considering in quantitative terms whether or not to attack and how to attack. The submarine commander's considerations are given below.

A. When both sides are using optimal pure strategies, the submarines' attack success rate will be lower than the submarines; loss rate ($v < 1$). Considered in terms of repeated encounters, this is a situation in which losses exceed gains for the submarines. In order to avoid combat in which victories do not outweigh losses, the submarines should avoid engaging destroyer combat formations.

B. If under specific circumstances the submarine must engage a small destroyer group, a way of improving tactics should be sought. We analyzed 250 simulations in which a single submarine attacked a single surface ship and discovered that two aspects of the assumed submarine operating principles needed improvement.

1. When the submarine detects its target at long range, the target's initial conditions have a clear effect on the outcome. When the target's bow angle is less than a limiting value, the submarine's success rate is between 40 and 50 percent, but when the bow angle exceeds this limiting value, the submarine's success rate is less than 10 percent; in the latter situation the probability of the submarine's being destroyed greatly exceeds the probability of its being victorious. If the submarine detects a target at intermediate distance at a bow angle exceeding the critical value it should give up the attack; but if

the target bow angle is smaller than the limiting value the submarine should strive to engage this ship.

2. About 80 percent of the occasions on which a submarine sank a surface ship occurred when the surface ship had unsuccessfully attacked the submarine. On these occasions the bow angle of the target was between 50° and 60°. Accordingly, after the submarine had avoided the enemy attack, it should rapidly determine the target's bow angle. It is between 50° and 60°, then it should rapidly position itself for the attack; otherwise it should withdraw immediately to avoid another attack by the enemy.

C. Our combat simulation results also indicate that if the submarine uses long-range homing torpedoes instead of straight-course aerodynamic torpedoes, increases its speed and improves its sonar countermeasures equipment so as to decrease the probability of detection by the enemy, increases its own detection range and the like, it will increase its win rate.

To summarize, we believe that the combat simulation is an advance in tactical research. In the combat problems with which we are dealing we generally are unable to carry out full-scale exercises in a situation fully resembling combat, and even if we could carry out such exercises we would be unable to perform large numbers of repetitions. Because of the effect of random factors, it would also be hard for us to rely on the results of one or two trials. If we used map or laboratory model simulations, the time required for each simulation usually would greatly exceed or at best would be equal to actual combat time. If we assume that each encounter between a submarine and a destroyer takes an average of 40 minutes, 1,500 tests would require 1,000 hours, equivalent to half a year, while with a 709 computer, 1,500 trials can be compressed into a few hours of simulation time, yielding statistical results. Accordingly, the combination of computers and combat simulations methods should be an inseparable part of military systems engineering; it is a branch of military command and tactical research which urgently requires broader utilization and development.

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Ship Measures Against Bombing

Beijing XITONG GONGCHENG LUNWENJI [SYSTEMS ENGINEERING PAPERS] in Chinese Jul 81 pp 56-61

[Article by Sun Shaoguang [1327 4801 0342], Huang Xinghui [7806 1198 1920] and Xiong Jiguang [3574 0679 0342], Unit 38641, PLA: "Preliminary Discussion of Optimal Methods of Defense Against Enemy Low-Altitude Horizontal Bombing for a Certain Type of Ship"]

[Text] I. Formulation of the Problem and Description of the Conditions

Bombing conducted by aircraft at an altitude (H) of 100 to 1,000 meters is called low-altitude horizontal bombing. This is still one of the likely methods of attack by enemy aircraft.

When a ship underway detects an enemy aircraft making a bombing run it can use medium- or small-caliber antiaircraft guns against within their effective range. Although the questions of choice of electronic countermeasures or of the moment of firing or type of fire of antiaircraft weapons are important, the present article focuses on the effect which the ship's maneuvering has on antiaircraft defense and evasion effectiveness. Ship maneuvering has always been recognized as a last resort in dealing with attack. It can alter the range deviation a and lateral deviation b of the center of the bomb impact dispersion pattern relative to the ship, as well as the angle α between the ship's heading and the bomb trajectory, thus changing the hit rate; but it also changes the number of guns engaged in repelling the attack and to a certain extent decreases the antiaircraft guns' accuracy. Accordingly the question arises as to how to select types of maneuver (including the moment at which to start an evasive turn, the direction of the turn, the turning speed and the like) so as to minimize the probability of damage to the ship, thus achieving the best defensive measures.

Low-level horizontal bombing by enemy aircraft generally involves stick bombing by a formation or single aircraft; aircraft with a small bomb load may use cluster bombing. In terms of the bomber characteristics and statistical data on common attack types, we can use the following attack conditions.

—The enemy aircraft conduct stick bombing in three-plane V formation from an altitude of 600 m. The aircraft are 60 m apart, with sighting by the leader. Each aircraft drops a stick of six 250-kg bombs with a spacing of 20.8 m. The aircraft speed V_d is 200 m/sec. The horizontal distance to the beginning of the bombing run is D_3 = 500 m and the sighting time is 16 seconds; the horizontal distance to the bomb release point is $D_8 \approx 1,800$ m. The probable range and lateral deviation of the bombs are 73.8 and 57.7 m respectively.

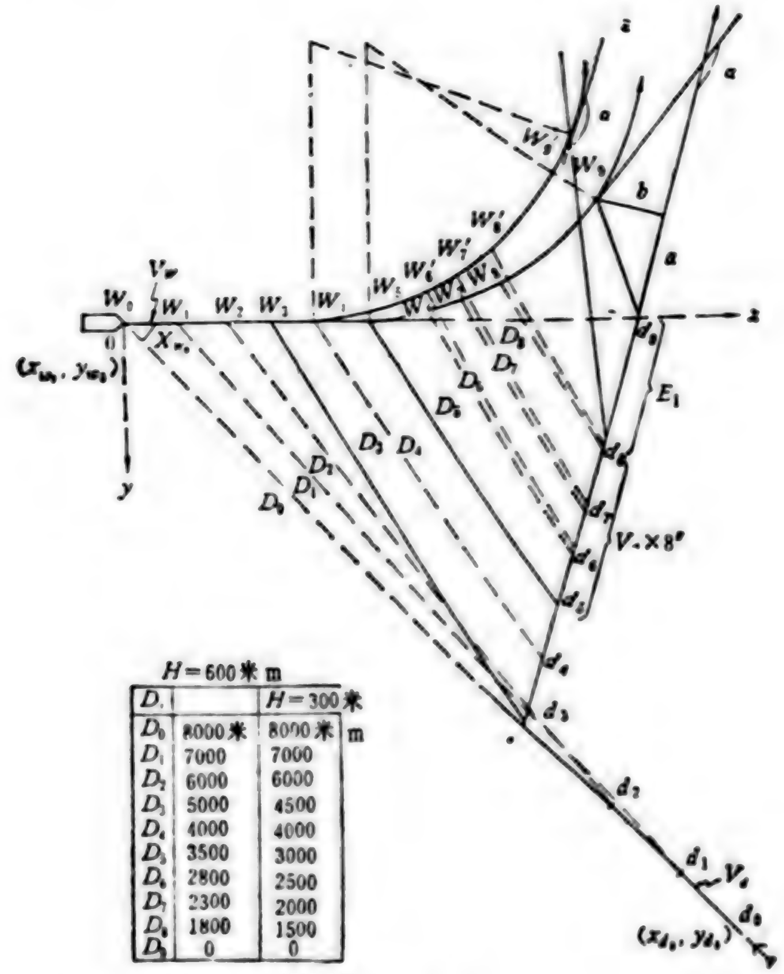
--A single aircraft carries out cluster bombing (two 250-kg bombs) at an altitude of 600 m with the other conditions as above.

--An enemy aircraft at 300 m carries out stick bombing (six 250-kg bombs): V_d = 200 m/sec, D_3 = 4,500 m, sighting time 15 sec, $D_8 \approx 1,500$ m, bomb spacing 10.8 m. Bomb deviation 67.5 m range, 52.7 m lateral.

The basic combat scenario (see Figure 2.1) is as follows.

Starting at point d_0 (relative to ship, the bow angle is X_{W_0} and the distance is D_0) the aircraft approaches the ship at velocity V_d on a heading $\overline{W_0 d_0}$; at point d_3 it turns into attack heading $\overline{d_3 d_8}$, sights, and if not destroyed by antiaircraft fire, releases its bombs at d_8, then withdraws.

The ship opens fire with medium-caliber guns at W_0, and with small-caliber guns at W_4, and continues firing until the aircraft is destroyed or the bombs are released (ship at W_8). While firing, the ship can make an evasive turn at distance D_j ($j = 0, 1, \cdots, 9$) and continue turning until the bombs have fallen, after which it resumes its original course.



D.	$H = 600$ 米 m	$H = 300$ 米
D_0	8000 米	8000 米 m
D_1	7000	7000
D_2	6000	6000
D_3	5000	4500
D_4	4000	4000
D_5	3500	3000
D_6	2800	2500
D_7	2300	2000
D_8	1800	1500
D_9	0	0

Figure 2.1

In low-altitude horizontal bombing, the minimum time required for the enemy aircraft to perceive and recognize the ship's turn is 5 seconds, and the minimum time required thereafter to resight is 3 seconds. Accordingly, if the ship begins its turn less than 8 seconds before the enemy aircraft drops its bombs, the enemy aircraft has no time to resight before releasing its bombs. As shown in Figure 2.1, if the ship turns at W_5 or later (distance D_5) the enemy aircraft cannot resight and the bomb dispersion center point will be at d_9, so that a and b will not be equal to zero. If the ship begins to turn before W_5, the enemy aircraft has time to resight and the bomb dispersion center will coincide with the ship's center of area, so that a and b will be equal to zero. Accordingly, we take W_5 as the dividing point and treat the situation as two cases.

II. Mathematical Model

A. Target Function and Variables To Be Selected

The probability that the aircraft is not hit by the antiaircraft fire before releasing its bombs is Q_d; the probability that before the aircraft can be destroyed it achieves at least one bomb hit is P_W; thus the ship's damage probability is

$$P_s = Q_d \cdot P_W$$

The ship begins to turn at distance D_j and the turning direction is z and the angular speed of the turn is ω_z: these are the variables that must be specified. Different values of D_j, z and ω_z correspond to different values of Q_d and P_W. Q_d and P_W are nonlinear functions of D_j, z and ω_z. If we use the equation given above as the target function, the problem is to find a set of values of D_j, z and ω_z which satisfies the equation

$$\min \{P_s = Q_d(D_j, z, \omega_z) \cdot P_W(D_j, z, \omega_z)\}.$$

On the basis of actual ship equipment and command procedures, we specified 10 distances D_j; z was specified as two directions, toward and away from the enemy aircraft; ω_z was specified as a turning speed of 2°/sec (because the optimal value of ω_z had already been obtained using another method). In our solution, we used 13 different values of the bow angle X_{W0} at which the enemy aircraft appears, ranging from 0° to 180° (at 15° intervals). For the Q_d and P_W of each X_{W0} we took $\omega_z = 2^\circ$ and used different values of D_j and z, obtaining different values of P_s, then found min P_s to select the optimal defensive strategy. We call this method the "fixed-point root-extraction optimization method."

B. System of Parametric Equations

1. Ship-Aircraft Equations of Motion

In the system of plane rectangular coordinates xOy (see Figure 2.1) the ship's coordinates are represented as (x_{Wj}, y_{Wj}) and the aircraft's coordinates as (x_{dj}, y_{dj}). The ship's starting point is W_0, its bearing is ox and its speed V_w; the aircraft's starting point is d_0, its heading is d_0W_0 and its speed is V_d.

When the equations of motion are used to find the coordinates of all the points d and W, we can calculate the five parameters needed to find Q_d and P_W, i.e. t_j, X_{W_j}, α, a and b.

The quantity t_j is the time required for the aircraft to move from D_0 to D_j; X_{W_j} is the bow angle of the aircraft when it is at the point d_j. Both t_j and X_{W_j} are functions of the specified parameters D_j, z and ω_z and the initial coefficients H, X_{W_0}, D_0, V_W and V_d.

The quantities α, a and b are not only functions of the specified variables and the initial parameters, but also are related to the horizontal distance D_B at which the airplane releases its bombs, the bomb trajectory E_1 and the bomb falling time t_ℓ.

2. The Probability Q_d That the Aircraft Is Not Destroyed by Antiaircraft Fire

We discuss the air attack in two stages. The first stage extends from the time when the medium-caliber guns open fire until the small-caliber guns open fire, when only the medium-caliber guns are being used against the aircraft. The second stage extends from the time at which the small-caliber guns open fire until the aircraft drops its bombs: during this time the medium and small caliber guns are both firing, but in our calculations we equate the effectiveness of the medium-caliber guns to that of the small-caliber guns.

Let $P^{(1)}$ and $P^{(2)}$ be the probability of destroying the aircraft in stages 1 and 2 respectively, let N_1 and N_2 be the average number of shells which must be fired by medium- and small-caliber guns respectively to destroy one enemy aircraft, and let $m^{(1)}$ and $m^{(2)}$ be the total number of projectiles fired by the medium-caliber and small-caliber guns respectively against the aircraft. Then

$$Q_d = 1 - \{P^{(1)} + (1 - P^{(1)})P^{(2)}\},$$

where

$$P^{(1)} = 1 - \left(1 - \frac{1}{N_1}\right)^{m^{(1)}},$$

$$P^{(2)} = 1 - \left(1 - \frac{1}{N_2}\right)^{m^{(2)}}.$$

3. The Probability P_W That the Aircraft Scores at Least One Bomb Hit

We denote the probabilities that the aircraft scores at least one hit in distance terms and direction terms by P_L and P_B respectively, so that $P_W = P_L \cdot P_B \cdot$ the quantities P_L and P_B are functions of α, a and b, and are also related to the length, breadth, height and speed of the ship, and the number of enemy aircraft, their spacing in the formation, the altitude at which they drop their bombs and their speed, direction and number, the spacing of the bombs in the stick, the angle of fall of the bombs and their probability distribution.

III. Analysis of Solution Results

Some of the results obtained are presented in Table 1.

Table 2.1 Some Results of Calculations on Defense Against Low-Level Horizontal Bombing With ω = 2°/sec (Q_d, P_W, P all given as percentages)

		X_{W_0}	0°	30°		60°		90°		120°		150°		180°
		s		背 A	向 T	背 A	向 T	背 A	向 T	背 A	向 T	背 A	向 T	
formation, stick bombing	编队连投	Q_d	100	79.7	86.3	82.9	85.7	82.3	85.9	78.2	77.7	81.3	73.1	100
		P_W	7.78	13.1	6.47	11.5	7.72	7.75	7.72	6.97	15.2	6.63	11.4	7.73
		P_{min}	7.78	10.5	*5.59	9.57	*6.62	*6.38	6.63	*5.45	11.8	*5.39	8.38	7.73
		D_j	D_0	D_0	D_9	D_0	D_9	D_1	D_0	D_9	D_1	D_9	D_0	D_0
single plane, stick bombing	单机连投	Q_d	100	77.1	83.3	81.4	84.8	82.0	84.3	80.0	69.8	79.3	71.1	100
		P_W	1.04	3.17	0.80	3.01	1.04	1.04	1.55	1.04	4.45	0.84	2.66	1.04
		P_{min}	1.04	2.44	*0.67	2.45	*0.88	*0.85	1.31	*0.83	3.11	*0.66	1.89	1.04
		D_j	D_0	D_0	D_9	D_0	D_9	D_0	D_0	D_9	D_9	D_9	D_9	D_9
single plane, cluster bombing	单机齐投	Q_d	98.2	85.4	86.3	82.6	80.3	79.5	79.0	78.2	77.7	81.3	78.8	98.7
		P_W	1.05	1.11	1.04	1.09	1.13	1.13	1.14	1.10	1.14	1.09	1.12	1.10
		P_{min}	1.05	0.95	*0.90	0.94	*0.90	*0.90	0.90	*0.86	0.89	*0.88	0.88	1.09
		D_j	D_9	D_9	D_9	D_9	D_9	D_9	D_9	D_9	D_9	D_9	D_9	D_9

Key: T = towards; A = away

A. Analysis of the Probability P_W That the Aircraft Has at Least One Bomb Hit and the Probability Q_d That It Is Not Destroyed by Antiaircraft Fire

P_W is related to α, a and b; the effects of these quantities on P_W differ with the type of bombing.

Figure 2.2 shows that in stick bombing by formations and by individual aircraft, changes in α (when $D_j = D_9 = 0$ m, X_{W0} is close to α and can be treated as equal to α) cause changes in P_W by factors of 2.2 and 5.1 respectively; the values $P_{W_{max}}$ for both these types of bombing occur at $X_{W0} = 90°$, while $P_{W_{min}}$ occurs at $X_{W0} = 0°$. The angle $X_{W0} = 90°$ is the most advantageous approach angle for the enemy in order to maximize the quantity P_W in stick bombing, while $X_W = 0°$ (or 180°) is the least favorable angle. When a and b are not equal to zero, the value of P_W is changed, but never by more than 100 percent. Accordingly, in low-altitude stick bombing, α has the primary effect on P_W, while the effect of a and b is secondary.

It can be seen from Figure 2.3 that Q_d is relatively little affected by the type of bombing used. $Q_{d_{max}}$ occurs at $X_{W0} = 0°$ or 180° (minimum attach success), while $Q_{d_{min}}$ occurs at $X_{W0} = 120°$ (maximum attack success). Differences in X_{W0} (α) can change Q_d by a factor of up to 1.4.

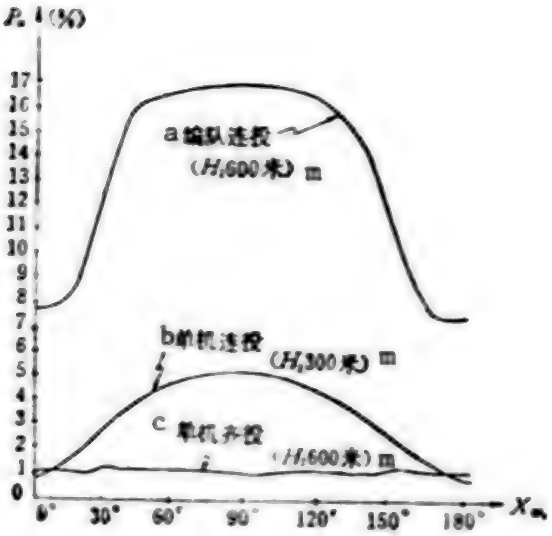


Figure 2.2 Plot of P_W Against X_{W_0} (for $D_j = D_9$)

Key:
- a. Stick bombing by formation
- b. Stick bombing by single aircraft
- c. Cluster bombing by single aircraft

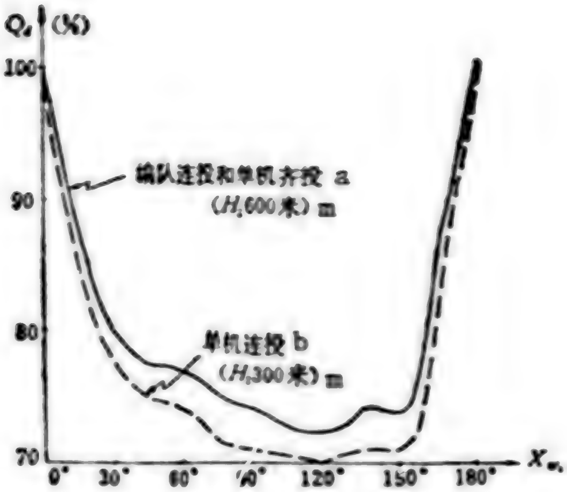


Figure 2.3 Plot of Q_d Against X_{W_0} (for $D_j = D_9$)

Key:
- a. Stick bombing by formation and cluster bombing by single aircraft
- b. Stick bombing by single aircraft

As the foregoing analysis indicates, the optimum solution for stick bombing by formations and single aircraft is determined by the location by which $P_{W\min}$ occurs, while $Q_{d\min}$ is a secondary factor. When the aircraft use cluster bombing at 600 meters altitude, because when $D_j = D_5$ the value of P_W can vary by a factor of 1.14 to 1.24 and Q_d can vary by a factor of 1.07 to 1.18 (see Table 2.2), P_W is still the main optimization factor. A particularly striking point is that no matter what the value of X_{W_0}, the value $P_{W\min}$ always appears at D_5 (because turning by the ship at this point produces the maximum values of a and b).

Table 2.2 Comparison of Change in Q_d, P_W for Cluster Bombing by Single Aircraft (Q_d, P_W given as percentages)

X_{w_0}	0°	30°	60°	90°	120°	150°	180°
		向 T	向 T	背 A	背 A	背 A	
Q_d(D_5 时) time D_5	98.76	86.35	82.17	79.57	78.25	81.32	98.74
$Q_{d\min}$	86.44	79.70	76.77	73.44	72.08	73.16	83.95
比值 ratio	1.14	1.08	1.07	1.08	1.09	1.11	1.18
$P_{w\max}$	1.29	1.29	1.29	1.29	1.29	1.29	1.29
P_w(D_5 时) time D_5	1.05	1.04	1.09	1.13	1.10	1.09	1.10
比值 ratio	1.23	1.24	1.18	1.14	1.16	1.18	1.16

Key: T = towards; A = away

B. Analysis of Ship Damage Probability P_s and the Specified Variables

In this article we take the solution min P_s as indicating the optimal defense plan. But the solution min P_s is primarily dependent on the point at which $P_{W_{min}}$ occurs. Table 1 indicates the following.

The optimal value of the turning direction z is the same regardless of which bombing method the enemy uses. When $X_{W0} < 90°$, min P_s for a turn toward the enemy aircraft is smaller than min P_s for a turn away from it, so that the optimal solution is to turn towards the enemy aircraft. When $X_{W0} \geqslant 90°$, min P_s for a turn away from the aircraft is smaller than min P_s for a turn toward it, so that the optimal solution is to turn away from it.

The distance D_j at which the turn is begun has the same optimal value for stick bombing by formations and by single aircraft. The basic principle for finding D_j in this case is to let α equal 0° or 180° and obtain the minimum of P_W. The actual distances D_j for the beginning of the turn are given in Table 1. When the enemy aircraft are using cluster bombing (H = 600 m), the optimal distance D_j is found by maximizing the displacement of a and b, so that the optimal solution is to begin the turn at point W_5 (time D_5) when the enemy aircraft will not have time to correct the bomb release. The horizontal distances between the aircraft and the ship corresponding to the values of D_j given in Table 1 do not take account of the change in horizontal distance between the time at which the commander gives the order and the time at which the ship begins to turn; in practical use this distance should be taken into account.

The optimal solution for turning speed ω_z is top speed and full rudder.

IV. Conclusion

Low-level horizontal bombing is a method of aerial attack on warships. Currently, low-altitude bombing is generally carried out at altitudes of 600-800 and 200-300 meters, more frequently in the latter range. But we have obtained the following conclusion regarding the way in which a certain type of warship should defend against these attacks.

When it can be determined that the enemy aircraft is using stick bombing, the evasive maneuver should be to turn broadside ($X_{W0} = 90°$) toward the enemy aircraft; when it can be determined that the enemy is using cluster bombing, the evasive maneuver should be to turn the bow or stern toward the enemy aircraft (approximately $X_{W_0} = 0°$ or 180°).

The warship's maneuvers are: 1. When $X_{W_0} < 90°$, turn toward the enemy aircraft; when $X_{W0} \geqslant 90°$, turn away from the enemy aircraft; 2. the distance D_j at which the turn is begun can be determined from Table 1; 3. the speed of the turn ω_z corresponds to top speed and full rudder.

These conclusions are subject to further verification.

Evaluation of Naval Weapons Systems

Beijing XITONG GONGCHENG LUNWENJI [SYSTEMS ENGINEERING PAPERS] in Chinese
Jul 81 pp 62-66

[Article by Ling Ruyong [0407 1172 6978], Naval Systems Engineering Department, Sixth Ministry of Machine Building: "Methods of Evaluating Naval Weapons Systems"]

[Text] Naval weapons systems are the basic force in naval combat. The extremely rapid development of science and technology has resulted in continual upgrading and diversification of these weapons' combat capabilities. The combination of ballistic missiles and nuclear propulsion has caused submarines to develop abruptly from a conventional force capable only of attacking surface ships from underwater concealment into a strategic weapons system capable of destroying major military and economic targets. Surface ships, from patrol boats and corvettes to cruisers and aircraft carriers, are all equipped with a variety of guided missiles and other weapons systems and with large numbers of electronic warfare and command and control systems, and are capable of taking on a wider range of naval combat missions. However, the missions, structures, sizes and combat tactics of the world's navies differ. This results not only from differences in scientific and technological level, but also from the countries' political, economic, strategic and geographic conditions. Against this background, the use of systems engineering methods can help policy-making organs reach scientific conclusions regarding the structure, combat employment and developmental requirements of naval combat systems.[1] Here we inevitably encounter the problem of how to make a quantitative evaluation of the effectiveness of various naval weapons systems.

Under our country's conditions, what are the military economic advantages of developing nuclear-powered ballistic missile submarines? If they are advantageous, how large should they be? These are evaluations questions which must be answered when drafting plans for the development of strategic weapons systems.

Since the early 1960's, some countries have built 80,000-ton guided missile cruisers. How much greater are their capabilities than those of conventional cruisers? What types of employment will yield the best and worst results? These are evaluation questions involved in the study of employment methods.

At every stage in the development of any new naval weapons systems, from selecting employment requirements and performance specifications, fixing prototype design and determining series size to subsequent reequipping and decommissioning, decision-making must take account of the capabilities expected to result from the program.

Quantitative evaluation of naval weapons systems cannot limit itself to technical characteristics. From the systems engineering viewpoint, the important thing is to evaluate the war-fighting and economic effectiveness of weapons systems in terms of the combat potential which they represent. This article is a brief discussion of quantitative evaluation methods.

I. Performance Characteristics and Combat Potential

Naval weapons systems are physical entities, composed of platform subsystems and armament subsystems, which are intended to perform specific missions. We generally use the following performance characteristics to describe these entities: 1. for the platform, rated and fully-loaded displacement, length, breadth and draft, maximum and economic cruising speed, cruising range and self-supporting capability, type of propulsion equipment, shaft horsepower, number of shafts, total personnel; 2. for the armaments, the types, numbers of installations, numbers of tubes, launch velocity, launch trajectory, propellant load and explosive charge, and the types, numbers and characteristics of the fire control and electronic warfare systems of guns, missiles and underwater weapons. The number of characteristics specified depends on the problem being investigated, but it must be limited. The numerical value of each characteristic can be chosen within a certain range, and accordingly there can be a variety of combinations of characteristics.

If the physical entities to which the different sets of characteristics apply meet the requirements of 1. overall system weight, balance and stability, 2. sufficient reliability of the subsystems under specific operating condition, and, 3. compatibility of these subsystems under typical operating conditions, then they are considered to represent feasible systems.[2] Accordingly there is a one-to-one correspondence between sets of characteristics and physical entities.

Any set of characteristics of a naval weapons system represents a certain combat potential, expressed in terms of the ability to destroy the enemy, survive, and accomplish such combat tasks as the following:

1. attacking and destroying various aerial, surface, underwater or shore-based enemy targets;
2. patrolling, picket duty and escort duty;
3. minelaying, minesweeping, amphibious operations and antiamphibious operations.

The question of how to express combat potential in quantitative form is one of the important problems of combat systems engineering. In practice we generally use displacement as a measure of the ship's combat capabilities. This is of value only as a rough estimate. Under modern conditions, it is entirely proper to use a system's ability to carry out combat tasks under specific circumstances, i.e. target destruction probability and expectation, survival probability, target detection probability and expectation, availability, reliability, response rate and the like, to evaluate its combat potential.[3] This is a more scientific method and is amenable to approximate calculation.

In the process of building, maintaining and using naval weapons systems, we naturally must consume certain quantities of resources, and accordingly we may also use cost effectiveness in the evaluation of combat potential.[4]

II. Evaluation Criteria

To select the design characteristics or choose the types of combat employment of either existing or new systems, we need specific evaluation criteria CR (also called evaluation principles, evaluation standards, evaluation functions and the like). These must correspond to the problem-solving goals and conditions; they must have a quantitatively describable relationship to the characteristics or types of employment to be selected; they must reflect the advantages and disadvantages of the system's capabilities; and they must be computable.[2-5]

Evaluation criteria for naval systems generally include:

1. indicators of combat availability and reliability;
2. indicators of engagement effectiveness;
3. indicators of resource expenditures.

Historically, a famous criterion which was successfully used was the sweep formula which the British Operational Research Society (ORS) developed during World War II for aircraft ship search.[5] This criterion was used for making scheduling computations, and analysis of the factors influencing it led to suggestions regarding improvement of aircraft sortie plans, training methods and the development of new search devices, thus greatly improving search and combat effectiveness. A wide variety of similar criteria for different situations are described in the literature (e.g. references 2-5).

In naval weapons system research and development, we need to consider the systems' effectiveness in carrying out n different combat missions during their service life. If a system's availability is R, its probability of survival before attack in each type of combat is S_i, its probability of destroying the target provided it survives is P_i, its expected resource consumption is E_i and its expected noncombat resource consumption during its service life is E_0, and the weighting coefficient for each type of combat is k_i, then we may use the following criterion:

$$CR = (R/E)\sum_{i=1}^{n} S_i k_i \ln[1/(1-P_i)],$$

where

$$E = E_0 + \sum_{i=1}^{n} E_i.$$

In order to calculate the criterion value, we need to construct a series of suitable criterion models.

III. Criterion Models

The effectiveness of a naval weapons system is manifested in a specific combat or resource environment. In addition to the characteristics of the system, these conditions also include the characteristics of the threat (typical targets, resource conditions, the natural environment, and the objectives, methods and operational principles of the two sides in combat. All of these conditions make up a larger system. We analyze these, identify the main contradictions, and abstract them into a numerical model, which we call an evaluation model. This model reflects the interrelationship between the evaluation criterion and the characteristics or types of operational employment to be evaluated and provides a method of computing the criterion.

Among the possible factors and requirements contained in evaluation criteria we may generally include: an availability model, an engagement model and a consumption model.

A. The Availability Model

This model reflects the mechanisms of the naval weapons system's ability to overcome natural, noncombat degradation and maintain a high degree of seaworthiness and battle readiness; it provides a method of computing system availability.

System availability is mainly determined by the availability of the propulsion subsystem and the various weapons systems.

Natural degradation results from technical and environmental factors. Technical degradation manifests itself as malfunctions produced by failure or wear of mechanical parts and assemblies and electronic components. In order to overcome or decrease this degradation, such measures as increased numbers of spare parts, improved design, institution of suitable maintenance and inspection systems and the like are used. A considerable amount of research has already been done in reliability and component replacement theory relevant to quantitative analysis in this area.[4] Environmental degradation involves a decrease in the system's ability to operate at forecast or designed characteristics in unfavorable weather or sea conditions, for example decreased cruising speed, unavailability of weapons because of violent rolling and pitching and the like. In order to overcome or decrease this type of degradation, such measures as added antiroll equipment or stabilized platforms, improvement of ship design and suitable navigation technology can be used. The results of ship handling theory can be used for quantitative estimation of environmental degradation effects.[3]

A system's combat reliability and battleworthiness can be analyzed in combination with the engagement model.

B. The Engagement Model

This model reflects the mechanism of a naval weapon's system's ability to destroy the enemy under combat conditions while itself surviving and provides a method of computing system survival probability and target destruction probability or expectation.

The engagement is a process characterized by the two combatants' use of measures to destroy each other and control their own damage while they are able to obtain information only gradually and never have complete information.

This process includes many indeterminate factors, because both sides make every effort to maintain secrecy about their armament capabilities, intentions and operational principles. Accordingly, it is impossible to construct an absolutely error-free model and it is necessary to resort to predictive, approximate models which reflect the main combat mechanisms.

Possible characteristics of future warfare indicate that repeated combat between single ships or small groups of ships will be the basic form of encounter. This unquestionably will also be the basis for large-scale encounters. Accordingly, the models described below are rather typical:

1. combat between individual ships, including submarine versus submarine, surface ship versus submarine, and surface ship versus surface ship;[6-7]

2. combat between small combat formations, including surface ship versus submarine or versus other surface ships and groups of aerial targets, and combat of helicopter or aircraft formations against submarines and the like;[8]

3. combat of escort groups against aircraft, surface ships or submarines, protection of sea areas and the like.[9]

Other models include amphibious operations, transport, minelaying and minesweeping and the like.[10] Since World War II, military operations research has reaped a rich harvest of results in investigating these models, such as theory of the employment of guided missiles, guns and underwater weapons, game theory, search theory, (Lanchester) dynamic combat theory, decision theory, electronic countermeasures theory and other relevant theories.[11-13] By using these results we can resolve many questions involving specific types of simple combat.

A basic type of encounter can be summarized by the following model. Suppose that side A's firing position control functions are $u_1(t)$ and $v_1(t)$, and that at time t side A has a probability $f_1(u_1, v_1)$ of destroying side B. Similarly, side B's firing position control functions are $u_2(t)$ and $v_2(t)$, and at time side B has a probability $f_2(u_2, v_2)$ of destroying side A. We denote the survival probability functions of sides A and B as $x_1(t)$ and $x_2(t)$ respectively. Because at any moment during the encounter it is almost impossible that both parties will be destroyed simultaneously, we can derive the following dynamic equations:[4]

$$\dot{x}_1 = (1 - x_1 - x_2)\, f_1(u_1, v_1)$$
$$\dot{x}_2 = (1 - x_1 - x_2)\, f_2(u_2, v_2).$$

In addition we have the initial conditions $x_1(0) = x_2(0) = 1$ and the final condition $x_1(T) = 0 \vee x_2(T) = 0$. These equations can be extended to cases in which both sides comprise several multilevel systems and where the destruction process consists of different levels of destruction.[8] If our goal is only to determine the survival probability functions x_1 and x_2 for the two combatants, then once we have specified the two parties' firing positions $u_1(t)$ and $V_1(t)$, where $i = 1, 2$, it is easy to obtain a solution. If our aim is to select optimal firing position control, we can introduce a suitable payoff function, then solve the problem as a differential game. Use of this modeling procedure to study relatively complex encounters is likely to be one of the important areas of future development.

C. Expenditure Model

Models of this type reflect the mechanism by which a naval weapons system consumes resources during its service life and provides a method of calculating the expenditure required to realize its capabilities. Such a model is particularly important in drafting a development plan, developing a new system or carrying out modernization and reequipment.[4,14]

The service life of a naval weapons system is generally 15 to 20 years. According to statistics for U.S. destroyers, total noncombat expenditures generally consist of the following categories.

1. development and production expenditures generally account for 28 percent, including expenditures on the construction of new production lines, the development and production of new materials and the like, in addition to which the effect of series size must be considered;

2. servicing and maintenance expenditures account for about 12 percent, including expenditures for constructing special bases, wharves and storehouses, scheduled maintenance, daily servicing, transport and replacement of parts and assemblies;

3. modernization and reequipping account for about 10 percent;

4. personnel training and provision of living accommodations and services, constant operating expenditures and partial war losses account for about 50 percent.

Depending on a system's design, the development and production process and the type of operation and employment, we can use technical-economic and mathematical statistical methods to construct an expenditure model corresponding to the availability model and encounter model.

The foregoing are the three main evaluation criteria to be discussed in this article. Since the early 1960's, one important tendency in the construction and solution of such models has been the extensive use of computer simulation models.[4] These methods are suitable when the factors in the model are very numerous, the factors operating in the process are complex, there is uncertainty and randomness and the mechanism is hard to analyze and express completely. To construct a model in such cases, we use a computer program to describe the objective process and its mechanisms; next we input the data and program into a computer and carry out a large number of computations, equivalent to the taking of samples, then carry out statistical analysis of the results to obtain the solution. Particularly as regards description of the type of encounter involved in the combat, statistical modeling is a very important practical method. It is as though we used the computer to carry out experimental encounters between two armies or sand-table exercises in order to investigate operational methods, evaluate weapons capabilities, improve the quality of field maneuvers and exercises, and the like. This method is extremely and widely used abroad.[15] Results have also been obtained from work done in this country, including the author's participation in submarine encounter modeling since 1976.

IV. Conclusions

This article summarizes quantitative evaluation methods for naval weapons systems in terms of the systems engineering approach to combat and economic effectiveness. This should be helpful in overcoming onesidedness resulting from exclusive pursuit of advanced technical characteristics in the development process without reference to combat and economic effectiveness.

Once the required criteria and evaluation model have been constructed, the model's inputs are the system's characteristics, operation and employment methods (or doctrines), and relevant environmental factors. Some of the factors in the last two categories must be evaluated or selected. The model's output is the evaluation criterion value. Decision-makers use this value to draw up optimal or rational decision or selection plans.

Because of the complexity of naval weapons systems, the models that are constructed must be somewhat simplified, and the correctness and reliability of the computed results is limited. Moreover, theoretical and experimental studies must be made in order to further improve existing methods. But this method helps decision-makers to decrease errors that could easily arise from immediate experience and to make more scientific and more rational decisions.

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Systems Engineering for Military Command,Control

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[Article by Liu Kejun [2692 0344 0193], National Defense Scientific and Technical University: "Systems Engineering for Military Command and Control"]

[Text] I. Introduction

Man is the most intelligent of creatures, with a "conscious dynamic role." When people engage in collective activity in the three great revolutionary movements of class struggle, production struggle and scientific experiment, to arrive at their common objective they must have various types of command and control processes. In class society, war is the highest form of class struggle, and its command and control is of particularly great importance. Military command and control naturally becomes the focus of discussion of command and control, and as a result of the rapid development of science and technology, the area taken in by military command and control is expanding steadily, and it has extensive influence. Its theoretical development has also stimulated the development of information science. Its engineering implementation is the main field of activity of systems engineering. Its theoretical and engineering accomplishments will inevitably stimulate engineering science to mature and gain in vigor.

The famous ancient military writer Sun Zi wrote in his book on war: "He who knows the other side and knows himself will be in no danger even in a hundred battles." Chairman Mao has also taught us that "The commander uses all possible and necessary methods of reconnaissance, then subjects the resulting information on the enemy's situation to examination in which he eliminates the nonessentials and incorrect information and retains the essentials and the true information; he then makes inferences about the essential situation, after which he adds to it information about his own situation, weighs the two sides against each other, arrives at a judgment, makes decisions and develops his plans." Thus it is necessary to discover the enemy's pattern of operations and use it as a basis for determining one's operations. The commander always needs timely, correct information on the actual strength of the two sides and the status of operations, and he needs a rapid, reliable method of transmitting his commands to his subordinate units. This can be considered to have been one of the key factors in successful military campaigns for the past 1,000 years. As a result of the extremely rapid development of science and technology since World War II, there have been great changes in the range, speed, precision and lethality of weapons systems. The concepts, methods, equipment and techniques of military command and control have undergone a corresponding transformation. This fact requires that modern military command and control systems have high reliability and survivability, good security and fast, precise maneuverability. If the capabilities of military command and control systems were unable to keep up with modern warfare, the results would obviously be serious, even unthinkable. Accordingly, they have already come to occupy an unprecedentedly important place in defense work, and in addition have come to be one of the key problems in determining whether strategic nuclear weapons can be effective. The technically advanced nations of the world already are energetically developing these systems. This focusing of scientific and technical knowledge on military command and control is considered to be the third revolution in military affairs.

Military command and control is an information processing procedure which provides an internal data flow up to the point of decision-making and an external command flow, transmitting orders. It does everything possible to assemble the elements involved in the making of decisions and to convert them into the most suitable form of presentation for decision-making use by the commander, as well as rapidly, correctly and reliably transmitting the commander's orders in implementation of his decisions. When these orders are being carried out, there will inevitably be new changes in the situations of the two sides. For more effective command and control, it is necessary to report these changes to the commander in timely fashion so that he can make new decisions based on them. Accordingly, this is a repeated, cyclic process. Military men all understand that "speed is of the essence in military affairs"; the faster the reaction time of this cyclic process the better. The speed of intercontinental ballistic missiles, the destructiveness of nuclear warheads and the existence of computerized military command and control systems require that the time needed to make decisions be short and that response be rapid. For example, if an aggressor suddenly attacks our country from a ballistic missile submarine or from the borders, we will have only about 10 minutes' warning, so that we must be able to react quickly.

Because we are a socialist country, our government has repeatedly declared to the world that under no conditions will China be the first to use nuclear weapons, but that it will respond effectively if attacked. Our country's current economic base has dictated that our strategic nuclear weapons cannot match those of the United States and the Soviet Union in numbers. In order to obtain a suitable and relatively precise capability for dealing with modern warfare and making a suitable response, we need to use advanced scientific and technical achievements to equip our military command and control systems so that they can aid the commanders in dealing with such aspects of warfare as confusion, lack of clear information, and uncertainty, strengthen organization and reliability, and enable our commanders to: (1) monitor closely the situations of the two sides and their development; (2) react quickly to alerts and threats; (3) dispatch the relevant units in timely fashion and carry out battle plans; (4) evaluate offensives, attacks and damage; (5) following a nuclear attack, to reorganize and command the forces; and (6) in protracted war, to manage the theater of operations; this will allow the commanders to bring their subjective activism into play in the objective situation and win resounding victories.

The foregoing focuses on strategic weapons, but at the tactical level too, military command and control systems are extremely important. They are used to elaborate combat plans, to direct combat and to provide dynamic information and strength assessments on the two sides in the battle zone. They provide a weapons and firepower control capability, process information from observation and communications facilities, and maintain communications with friendly force elements. Because modern science and technology focus on military affairs, the capabilities of military weapons systems are extremely great. When the ground forces are engaged in combat they are supported by naval and air forces, producing rapidly-changing three-dimensional combat in which the units have high maneuverability, and accordingly it is critical that the commander be equipped with a modern military command and control system.

II. Main Scientific and Technical Areas Involved

Observation and communications facilities allow timely insight into changes in the objective world. Data processing equipment has greatly improved the power and speed of processing of information and data on the objective world. These factors have greatly aided the commander's decision-making process. We may conclude that in technological terms, communications equipment and computers provided the material basis for the transformation in military command and control. Human behavioral science provides the commander with the biological conditions and reaction capabilities to master, operate and utilize this technical equipment and thus enables him to utilize it better. Communications, computers and people are the three basic factors of command and control; systems theory organically and harmoniously combines these three factors to achieve its objectives. The greatest influence is exercised in this field by: (1) microelectronics and large-scale integrated circuits; (2) digital information transmission systems; (3) ultralow frequency, very low frequency, microwave, laser, satellite and other communications facilities; (4) computers, particularly microcomputers, large-size computers, computer networks, distributed data processing and advanced teleprocessing techniques; (5) displays and intelligent terminals; (6) operations research, decision theory and signal processing, involving fast recognition and detection, determination of importance and implications, presentation of a variety of responses and estimation of their consequences; (7) modular systems design theory; (8) the principles and methods of systems engineering; (9) military command theory.

A. Communications

The primary concern here is how to use the various scientific and technical achievements described above in just the right way and to make integrated use of all types of communications facilities to assure that even in a nuclear war a free flow of military command information can be maintained.

B. Computers

In addition to meeting requirements regarding information capacity, reaction time, man-machine interface, time-sharing operation, distributed information processing and shared communications access it is also necessry to take full account of reliability, which is the most important factor in whether computers can be used in military command and control systems, and which can be improved by various measures. For example, it is possible to use backup techniques such as redundant machines and spare parts modular interchangeable design, maintenance and self-diagnosis techniques, automatic software diagnosis and testing and the like. Suitable attention must also be devoted to the information processing procedures in command and control, to some basic laws and principles regarding the computer used by the commander himself, to the commander's and operator's requirements and the ways of implementing them on the computer, to the computer's relationship to the entire system and its various elements, and to the use of computers to simulate and test command and control problems.

The main requirements affecting computer hardware configurations are speed, capability of simultaneous operation, reliability and cost. All new computer technologies have been utilized to assure that response time for the commander's information requests will be less than 3 seconds. If this requirement cannot be met, perceptual effectiveness will be decreased. At present, the weak link is input-output equipment.

As military command and control networks continue to expand, the commanders often need to review certain key summary data quickly and to review past and expected information on a real-time basis. This requires that the various levels of storage equipment, with their various speeds, be well coordinated so as to achieve maximum cost effectiveness. It should be borne in mind that different types of information have different access probabilities. For example, information whose access probability is about 90 percent accounts for only 35 percent of all information. By studying such laws and by rational design it is possible to bring the access speed of all information close to that of the fastest large storage devices in the system. As the amount of fixed reference information to which access is desired increases, laser and other mass storage equipment can be used. In addition, thorough use should be made of developments in microelectronics and integrated circuitry, and time sharing operating systems and communications satellite computer networks should be used in order to make thorough use of computer resources and improve overall system capabilities.

2. As regards computer software, because of the complexity reflected by military command and control systems, it is generally necessary to treat

programs and operating systems as a unity in order to thoroughly mobilize the capabilities of all components of the system, so that the commander need only specify the system operating state, check its correctness and make his final decision, thus minimizing the effort that must be expended by the operator and the commander. When a final decision is being made, the problems being considered are very complex, and accordingly, the complexity of the computer control level must be very great. Obviously it is very important that it be highly automated. Its compilation programs not only require a highly efficient machine language, but also high compilation speed. The languages used ideally should allow the programmer to select features from any level and to select the desired control level as needed. The structures of the computer languages used should be suited to the capabilities of military command and control systems. Because of time sharing and on-line and real-time operation are used in computer networks, the languages used must meet their flexibility requirements. As the complexity of decision-making increases, the concept of programming has been further developed. For example, the user can conveniently organize existing programs on the basis of his problem-solving experience in order to produce the needed software. The hardware can even be adapted to the requirements of the problem-solving software. In addition, military commanders need interactive languages to enable the system hardware to operate effectively and expeditiously on the basis of human intentions. In this context, attention should also be devoted to the problem of automatic input and output of the characters and local dialects characteristic of command and control in our army. Because of the characteristics of military command and control, officers requests are generally dynamic and changing, so that it is very difficult to specify in advance, completely and correctly, all of the command and control capabilities which software should have. Software work must adapt to these characteristics.

To summarize, hardware and software must be effectively coordinated so as ultimately to enable the commander to perform his command function by directly operating the computer, using ordinary language.

3. Behavioral Science

The main subject of study here is the commander's decision-making process. Thorough attention should be given to many characteristics of the commander's decision-making such as its game-like nature, security and the like. Only by studying ways of processing complex information into the most suitable form for presentation to the commander can it support optimal decision-making. In this context, the theoretical basis of systems research, namely operations research and the like, is extremely useful. It helps people seek theoretical models of functioning and optimize them. Much work still remains to be done in effectively using the military thought of famous ancient and modern, Chinese and foreign military experts and of Chairman Mao for the decision process. Because the decision-making process is very complex, it is not enough to rely solely on theoretical analysis: experience must also be used. But the actual combat environment generally is not available, and accordingly simulation and experimental techniques must be used. These are essential tools for developing military command and controls systems. In addition, they are an excellent means for training commanders to operate the system.

Furthermore, attention must also be devoted to the process of information interchange between commanders and the forms in which information is presented, in order to maximize their efficiency. Accordingly, visual and audio equipment should be used in integrated fashion, and in particular more use should be made of information display screens.

Because such new technologies as computers and electronic displays have now permeated military command and control systems, the personnel using them must have the requisite scientific knowledge and operating skill. Frequently, because training cannot keep up with advances in equipment, new systems cannot play their full role, for some commanders develop a tendency to use outmoded but familiar manual command and control methods. The effect of high-level commanders' inclinations in this regard is particularly great. Accordingly, it must be stressed that no matter how advanced the technology of military command and control systems is, all equipment must work to help the commander, because the commander is a key element in the system and the human is the key factor. When developing military command and control systems, it is critical that full consideration should be given to the commander's biological and psychological factors and that he should be enabled to master the relevant new technology and operating methods as rapidly as possible. Otherwise it will be difficult to make the machinery fully perform its function of assisting the commander.

4. Systems Theory

This field is concerned not only with things but also with people. Military command and control systems include many unpredictable factors and the technologies and theories of which they make use are developing rapidly. Accordingly, in order to adapt to these changes, recently the concept of continuous modernization has been developed, making use of modular system design concepts. This not only makes it easy to expand the system in the future, but also makes it possible to change the system's structure in response to changes in environment and use requirements. This type of system design theory is extremely well suited to military command and control systems.

In the past there was a certain overemphasis on the technical design of systems hardware and an underemphasis on the commander's requirements, which led to decreasing effectiveness. We should be aware that in military command and control systems, systems theory must make the person the central factor and organically coordinate the person, the machine and communications into an extremely effective military command and control system.

IV. Conclusion

To summarize, military command and control systems involve a wide range of scientific and technical fields. Some of the relevant theories and experience can be extended to social production and scientific experimentation, such as public safety command and control systems, aviation communications command and control systems, bank management systems, state planning commission management systems, weather forecasting systems, space flight command

and control systems, electronic education control systems, intelligence data reference systems, comprehensive medical diagnosis systems, automated engineering design systems, large-scale enterprise management systems and the like. Accordingly, all technically advanced countries have a strong contingent developing military command and control systems. They are of extremely great importance for promoting our country's four modernizations. At present, our country's technological level still lags considerably behind the world level in this area. In order to work successfully in this area we must create a high-level, centralized leadership structure, utilize systems engineering principles and methods to develop a unified, complete general plan, and develop standardization and universalization plans, so as to speed up the development of our country's military command and control systems and make a suitable contribution to carrying out our country's four modernizations!

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